Introduction

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After its emergence in the late eighties, MEMS (Micro-Electro-Mechanical-Systems) or MST (Microsystems Technology) has developed into billion $ commercial markets, in particular in the automotive, medical, and telecommunication fields. The Lecture Series will address applications in the aerospace field, which encounter unique challenges related to harsh environment conditions and reliability requirements. This Introduction will provide a brief introduction into the MEMS technology, discuss examples of commercial and potential aerospace applications, and introduce the lectures, which will focus on six specific aerospace applications.

MEMS are miniature devices, which integrate actuators, sensors, and processors to form intelligent systems. Functional sub-systems could be electronic, optical, mechanical, thermal or fluidic. MEMS are characterized by their close relationship to integrated-circuit components both in terms of manufacturing techniques and their potential for integration with electronics. One example of a true MEMS system, which will be discussed, is the "Smart Micro Skin" which combines sensors, actuators, and controller to detect and control flow separation at the leading edge of a delta wing.

Several manufacturing techniques are required to develop MEMS, including surface micromachining. In this process mechanical microstructures are fabricated on the surface of a wafer by depositing different types of layers. Deposited layers include structural layers, which form the final structures, and sacrificial layers, which are removed in the final stage of the fabrication through the edging process.

The advantages of MEMS are numerous. They include miniaturization (allowing distributed sensing and actuation coupled with redundancy), reduced cost of fabrication (through the use of microelectronics processing technologies), and real-time control (allowing on-line active process control and health monitoring). In addition, micro devices can control macro systems by using natural physical amplification characteristics of the system. For example, the control of flow separation at the leading edge of delta wings by micro actuators allows the control of the leading-edge-vortex position, which determines lift and moments.

Examples for MEMS commercial applications, which will be discussed, include digital micro mirrors for projectors and micro total analytical systems.

Many MEMS aerospace and military applications are being considered. Examples are micro jet arrays for flow control, IMUs (Inertial Measurement Units) for inertial measurement and navigation, fuze/safety and

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arming for munitions, health monitoring of machinery, and telecommunication for pico satellites. The MEMS aerospace applications are confronted with barriers and challenges, which are more severe than for commercial applications. This resulted in slow progress of inserting many of the potential MEMS aerospace applications.

Military MEMS applications are being addressed in the NATO RTO (Research and Technology Organization) MEMS Task Group AVT (Applied Vehicle Technology) –078. This Group is assessing potential applications, determining technology status and R&D needs, discussing barriers for implementation, and developing insertions strategies. The Task Group saw the need to enhance user and MEMS supplier interactions and to increase MEMS awareness as enabling technology for several applications. Because of this need, the Task Group has proposed these Lecture Series, which will provide an introduction into MEMS technology and then focus on six potential applications, namely micro-flow control, IMU, fuze/safety & arming, micro power, gas turbines applications, inventory and health monitoring of munitions. Also an introduction into MOEMS (Micro-Optical-Electro-Mechanical-Systems) will be provided.

INTRODUCTION

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RTO LECTURE SERIES “MEMS AEROSPACE APPLICATIONS”

MONTREAL, CANADA, 3/4 OCTOBER 2002

ANKARA, TURKEY, 24/25 FEBRUARY 2003

BRUSSELS, BELGIUM, 27/28 FEBRUARY 2003

MONTEREY, CA., USA, 3/4 MARCH 2003

OUTLINE

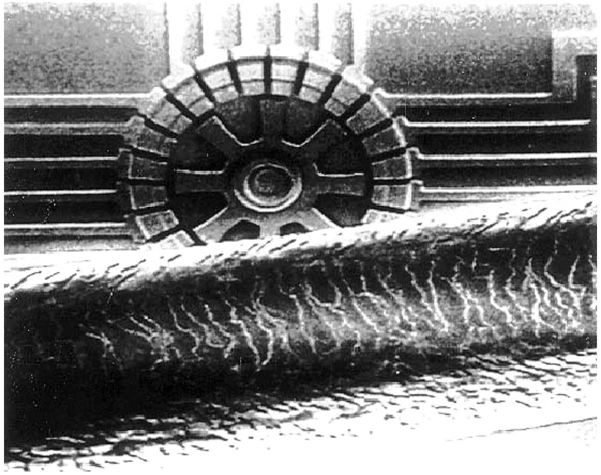
- FROM CURIOSITY TO BILLION $ MARKETS
- WHAT IS MEMS?
- WHY MEMS?
- EXAMPLES OF COMMERCIAL APPLICATIONS
- POTENTIAL AEROSPACE APPLICATIONS
- BARRIERS AND CHALLENGES FOR IMPLEMENTATION
- SELECTED AEROSPACE APPLICATIONS

FROM CURIOSITY TO BILLION $ MARKETS

- 1960
  - MICROSENSORS
- 1980
  - MICROACTUATORS
- 1988
  - MEMS
- 2002
  - (INKJETS)
  - AUTOMOTIVE SYSTEMS
  - BIOMEDICAL SYSTEMS
  - TELECOMMINICATION

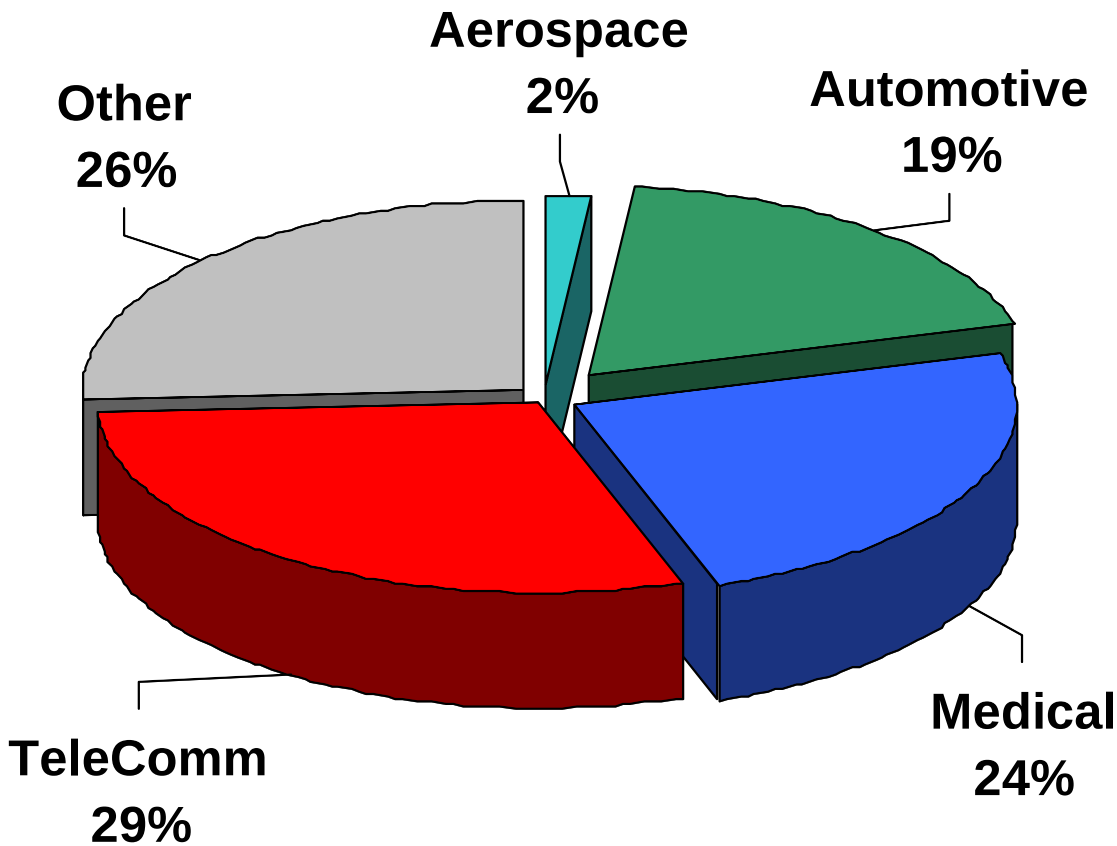
FIRST MICRO MOTOR

Micro-Electro-Mechanical -System
<u>MEMS</u>



UC BERKELEY, 1988

Global Market Segments



From Ed Hart
of Goodrich
Corporation

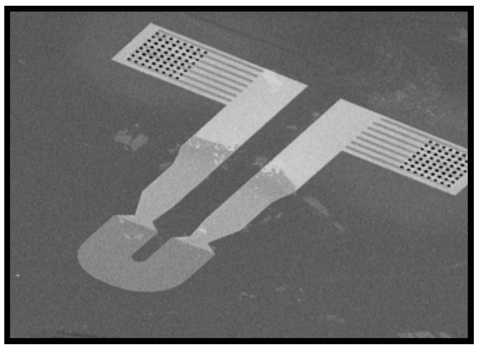
MEMS Component Sales in 2000: $3 Billion
Projected 5 Year CAGR: 60%

WHAT IS MEMS?

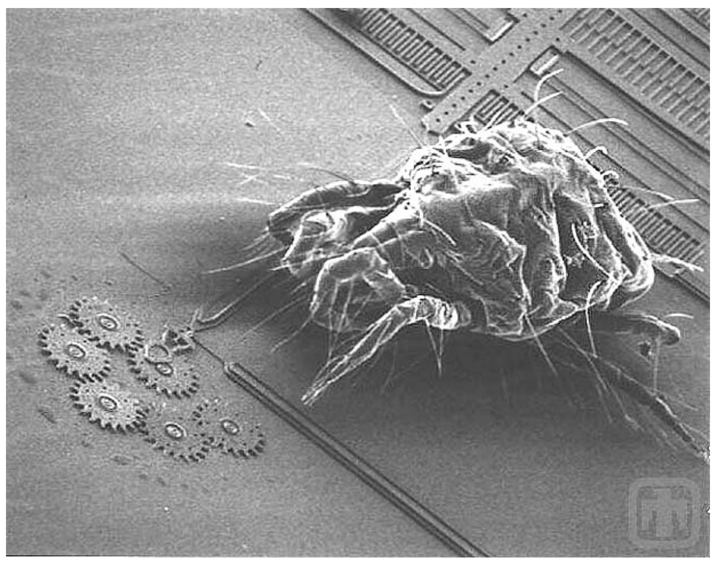
- MICRO-ELECTRO-MECHANICAL-SYSTEMS
  - MINIATURE DEVICES
  - INTEGRATION OF ACTUATOR, SENSOR, CONTROLLER / PROCESSOR
  - ELECTRONIC, OPTICAL, MECHANICAL, THERMAL AND / OR FLUIDIC FUNCTIONALITY
- WAY OF MAKING THINGS (DARPA)
  - INTEGRATED-CIRCUIT (IC) BASED MANUFACTURING TECHNIQUE AND INTEGRATION WITH ELECTRONICS
  - MICROMACHINING
- MICROSYSTEMS TECHNOLOGY

MEMS Components

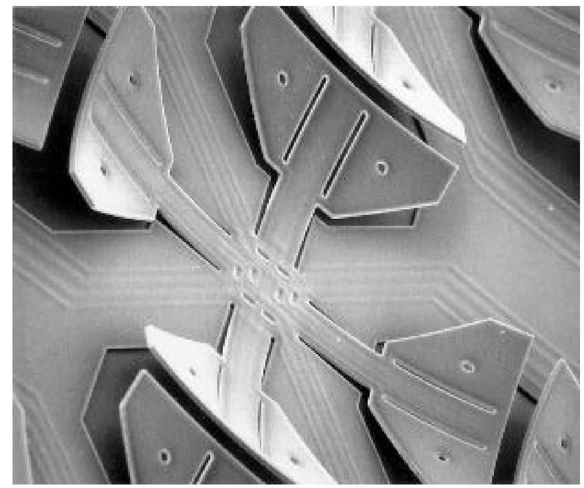
MEMS-based systems are physically small and integrate electrical and mechanical components.



Sensors

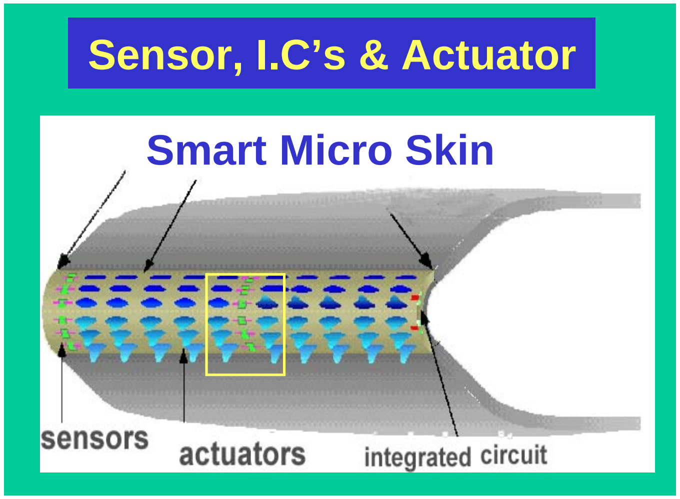


Mechanisms



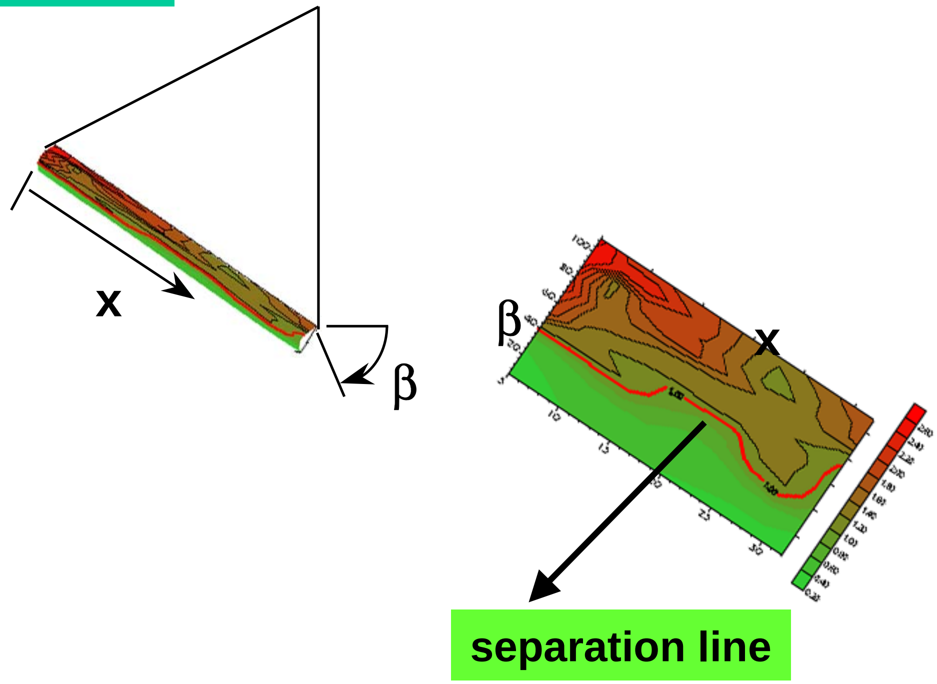
Actuators

Sensing and actuation at L.E.

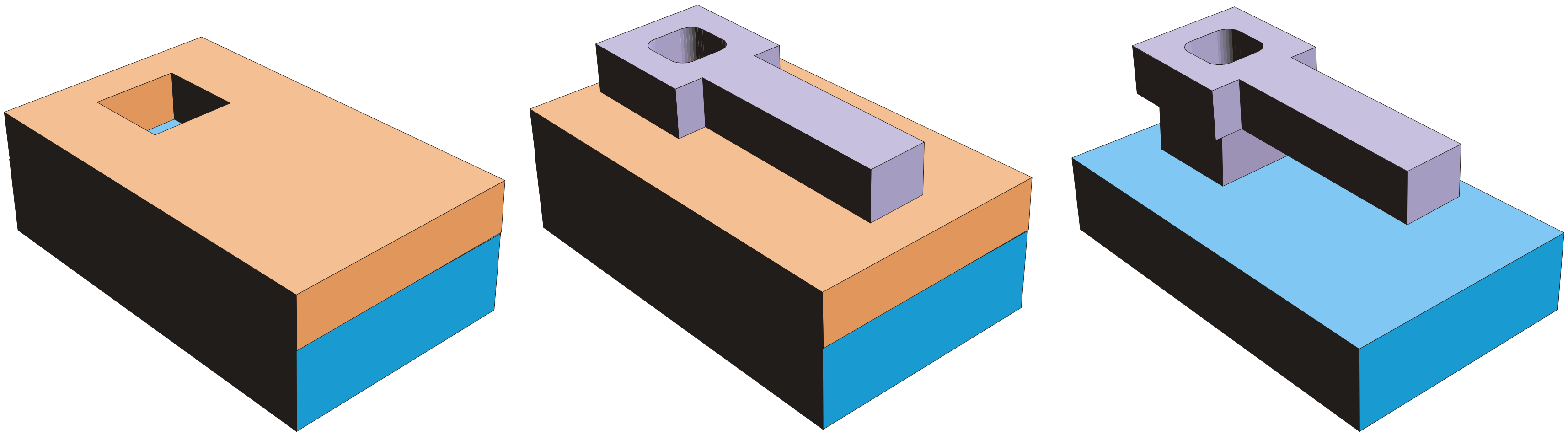


L.E.

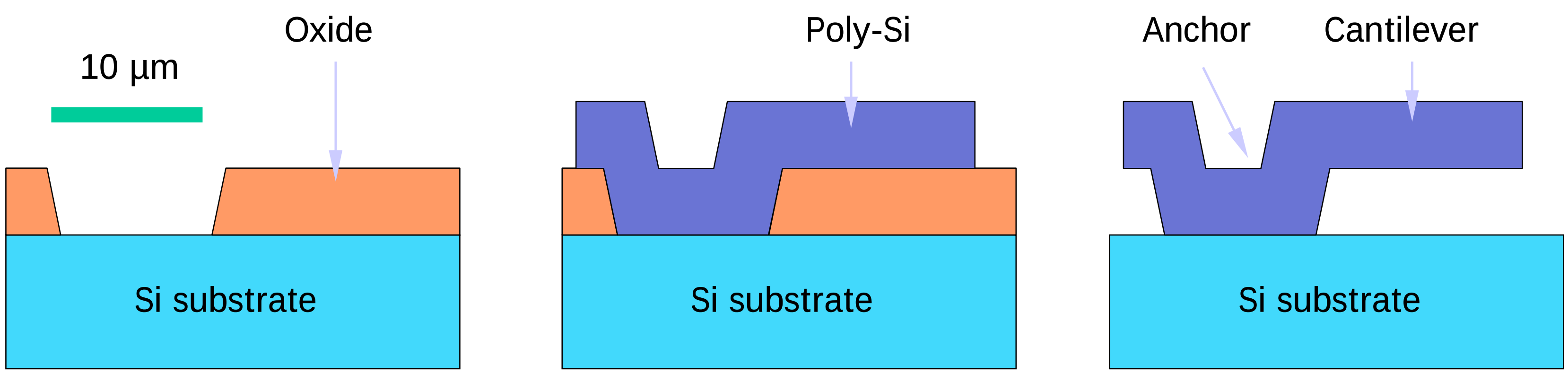
Small area - micro transducers
Curved surface



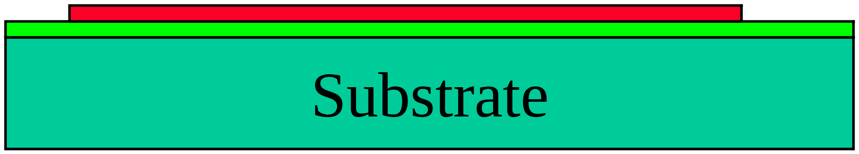
Surface Micromachining

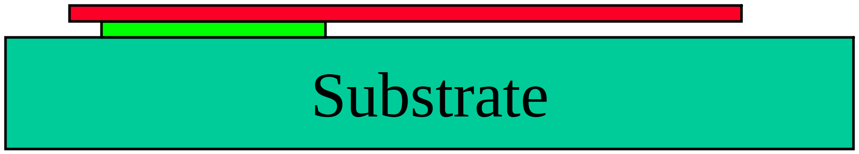


Deposit & pattern oxide ***Deposit & pattern poly*** ***Sacrificial etch***

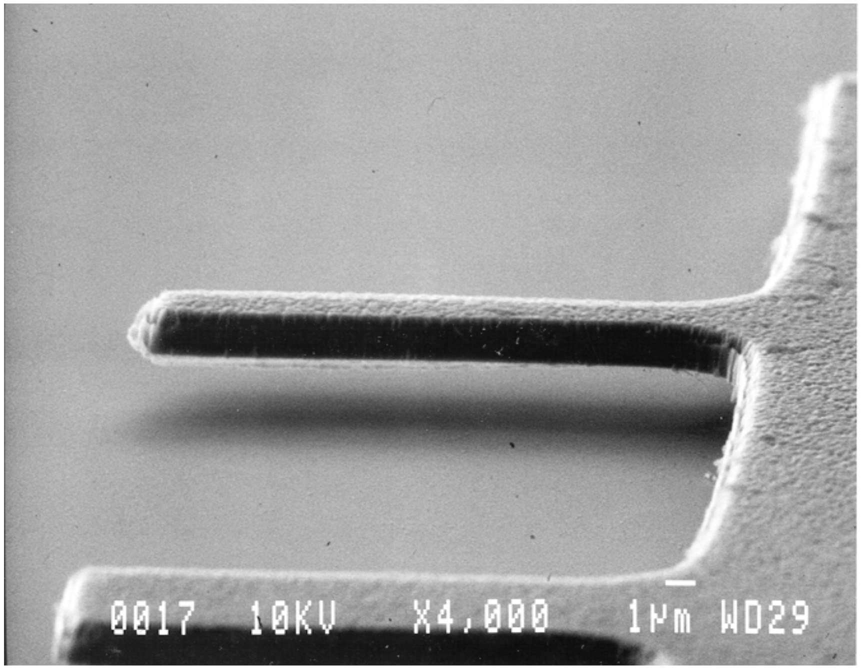


Simple Surface-Micromachined Structures

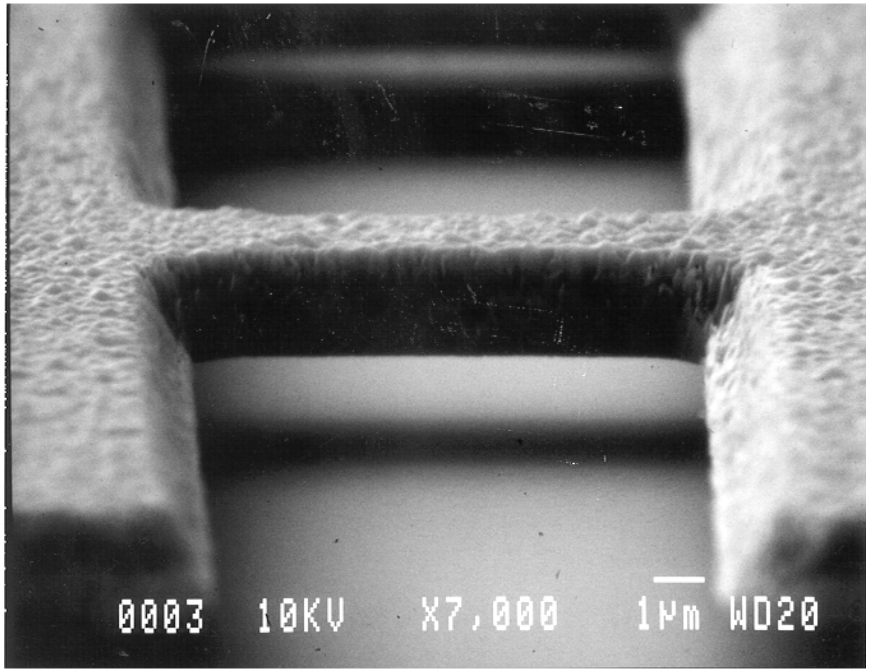




Sacrificial layer Structural layer



Cantilever beam

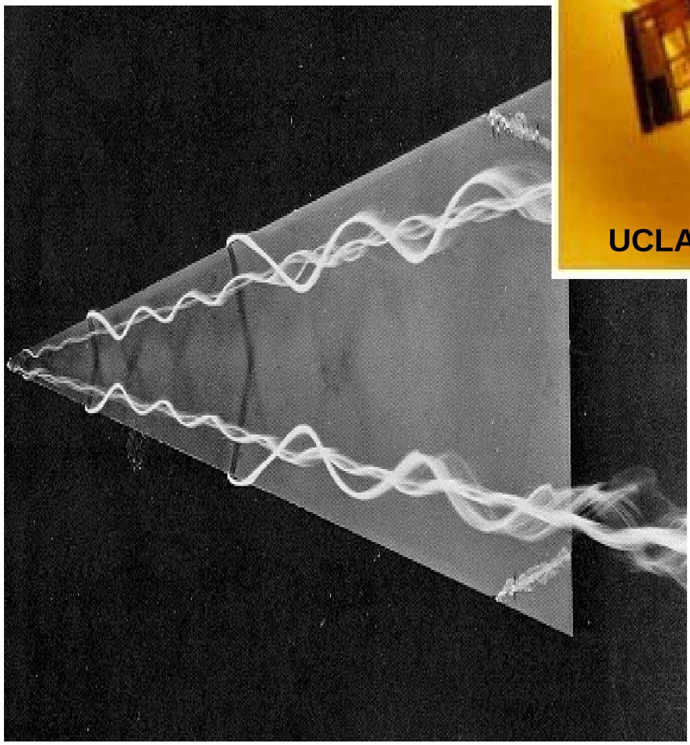


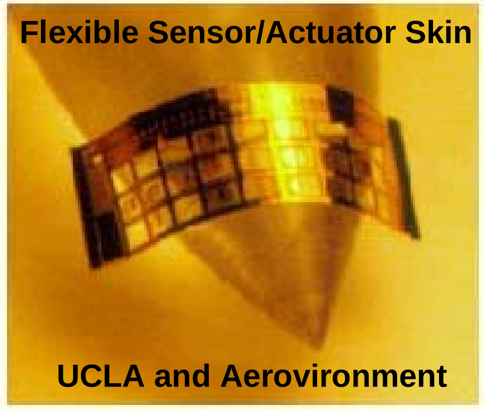
Doubly-supported beam

WHY MEMS?

- MINIATURIZATION
  - DISTRIBUTED SENSING AND ACTUATION COUPLED WITH REDUNDANCY
- REDUCED COST OF FABRICATION
- REAL TIME CONTROL
  - ON-LINE ACTIVE PROCESS CONTROL AND HEALTH MONITORING
- MICRO DEVICES CONTROL MACRO SYSTEM

MEMS Actuators for Aero Control





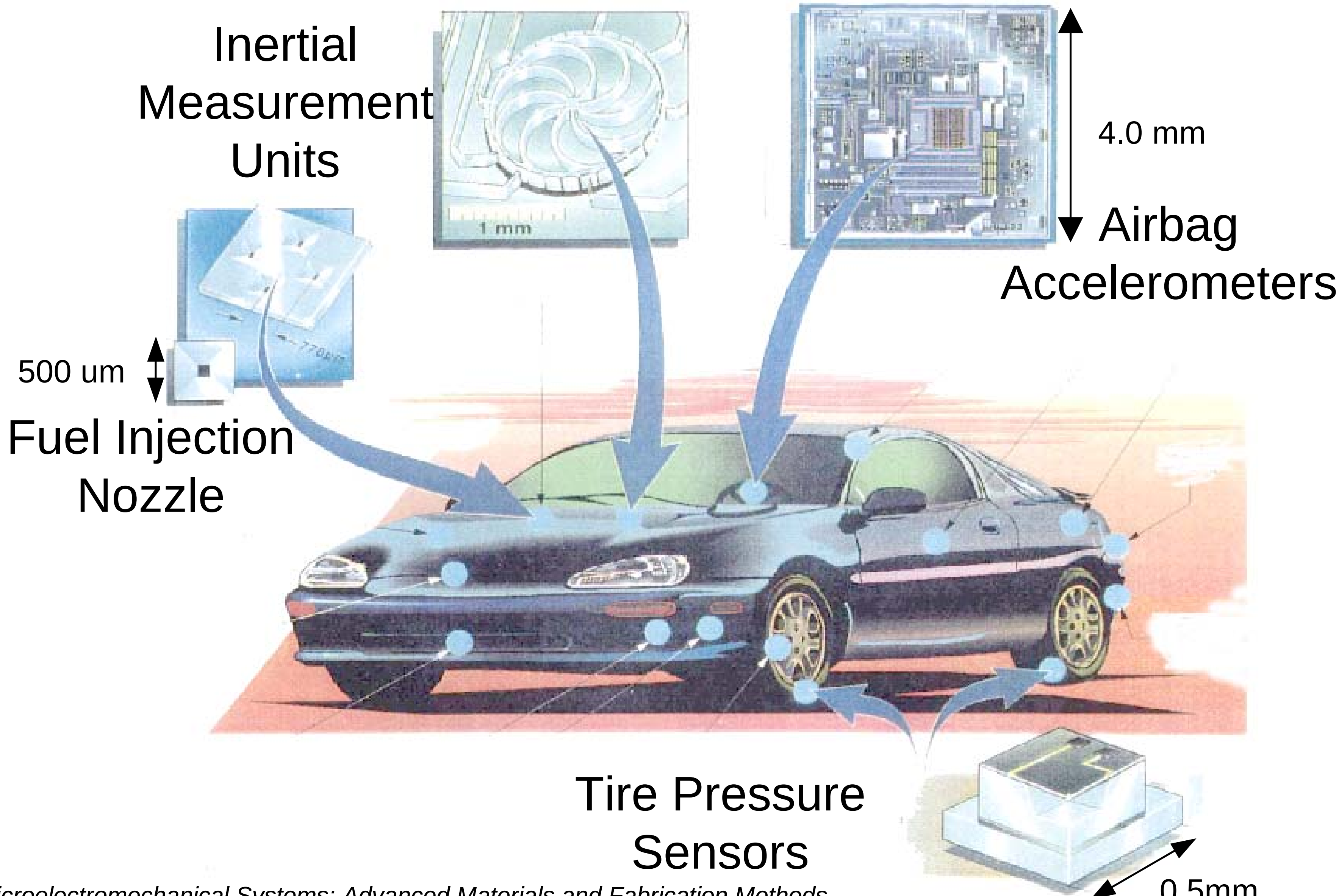
MEMS Actuator Array on the Leading Edge of Wing of 1/7 Scale Mirage III Fighter

UCLA and Aerovironment

COMMERCIAL APPLICATIONS

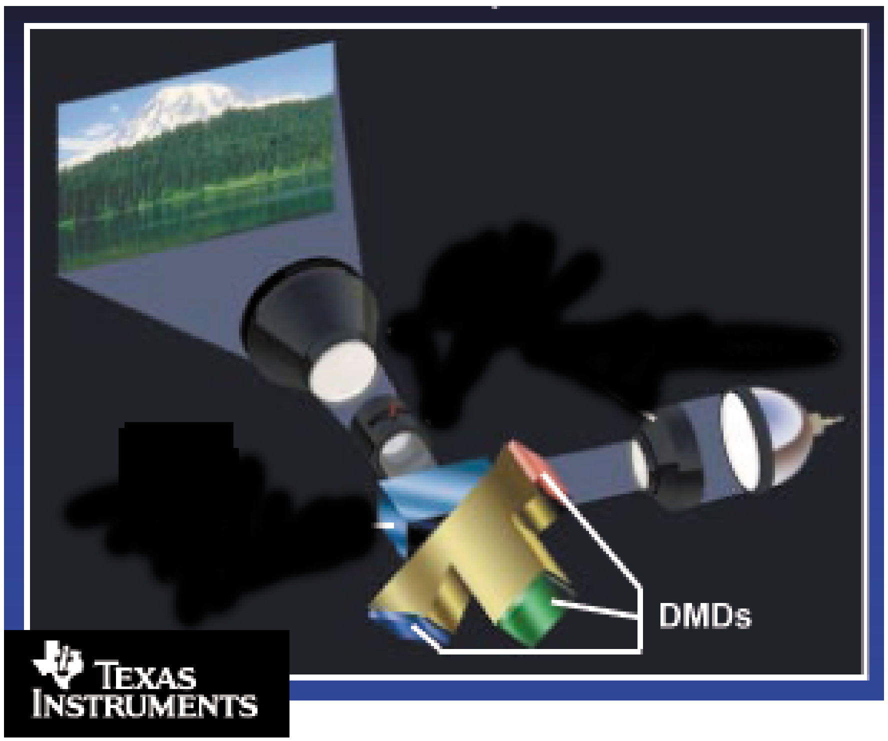
- AUTOMOTIVE MEMS SYSTEMS
- OPTICAL MEMS
- MICRO TOTAL ANALYTICAL SYSTEMS (TAS)
- COMMUNICATION / RF MEMS
- BioMEMS
- INSPECTION MEMS

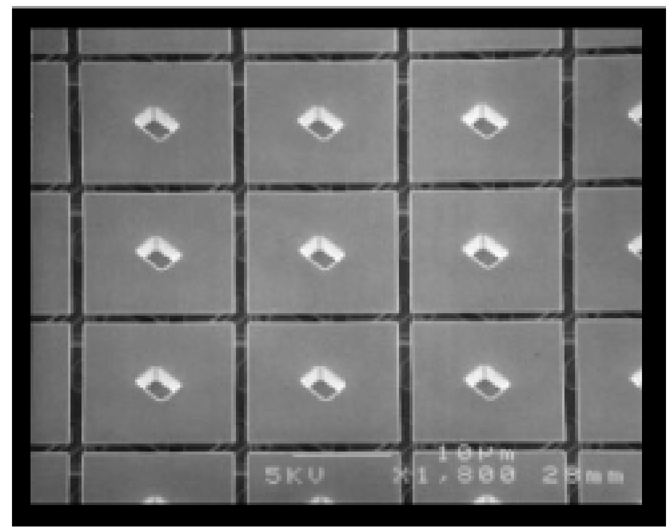
Commercial MEMS-based Products



Microelectromechanical Systems: Advanced Materials and Fabrication Methods

Digital Micromirrors for Sub-portable Projectors

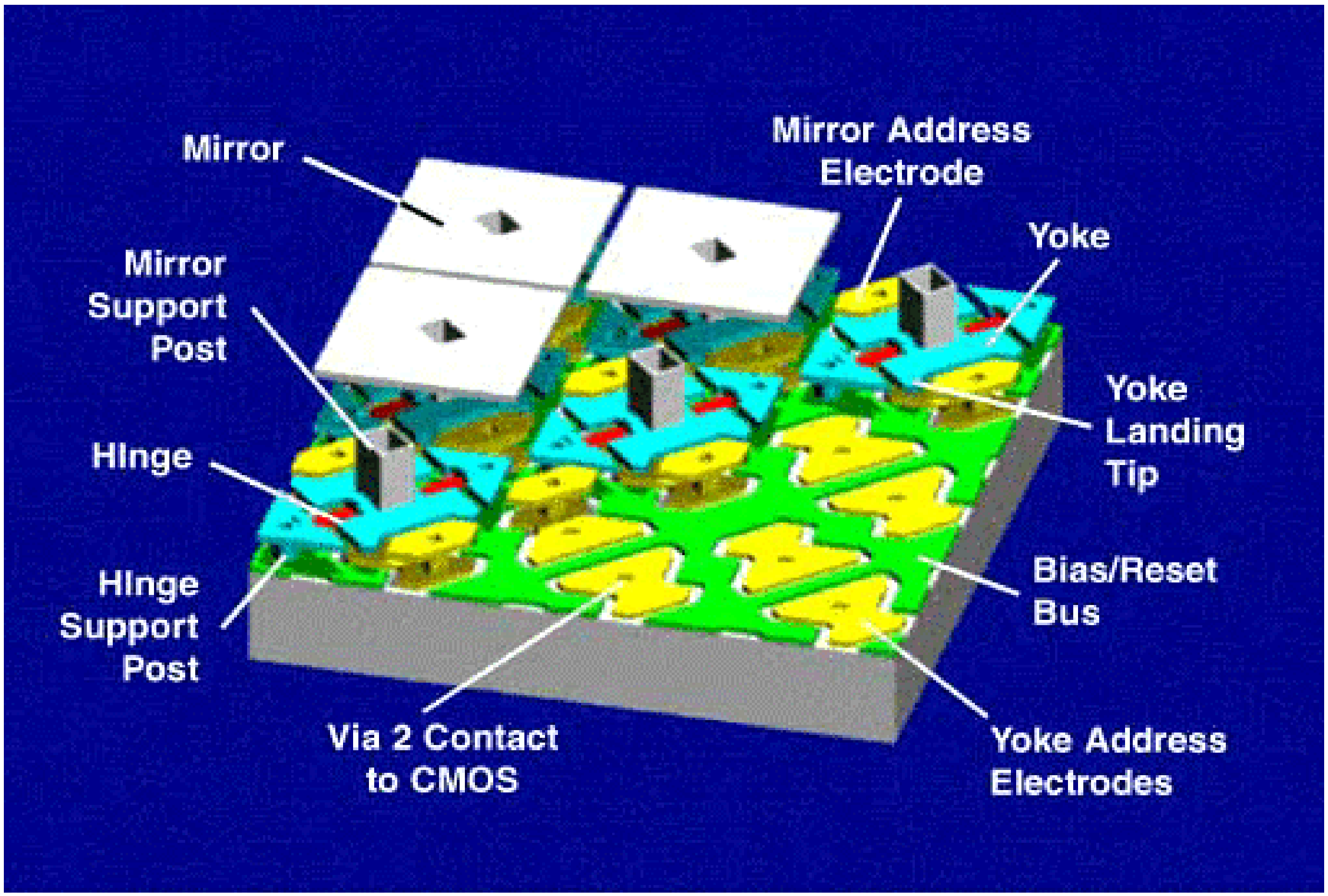




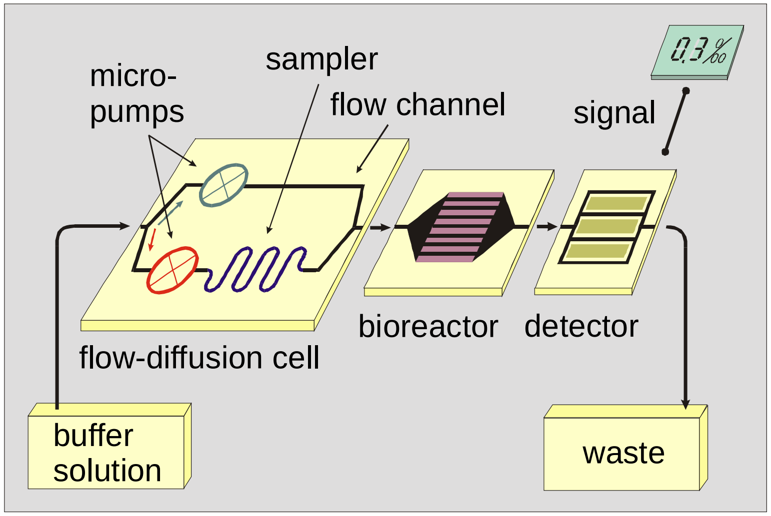
10 um

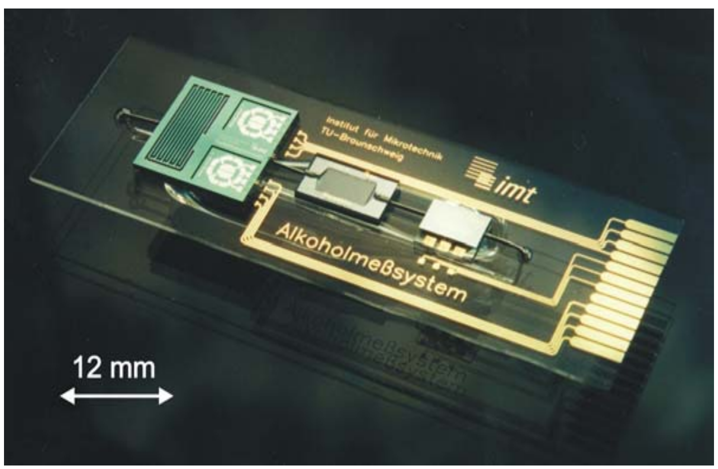
PLUS U3-880
- 2.9 lbs
- 1.9” x 9” x 7”
- SVGA (800 x 600)

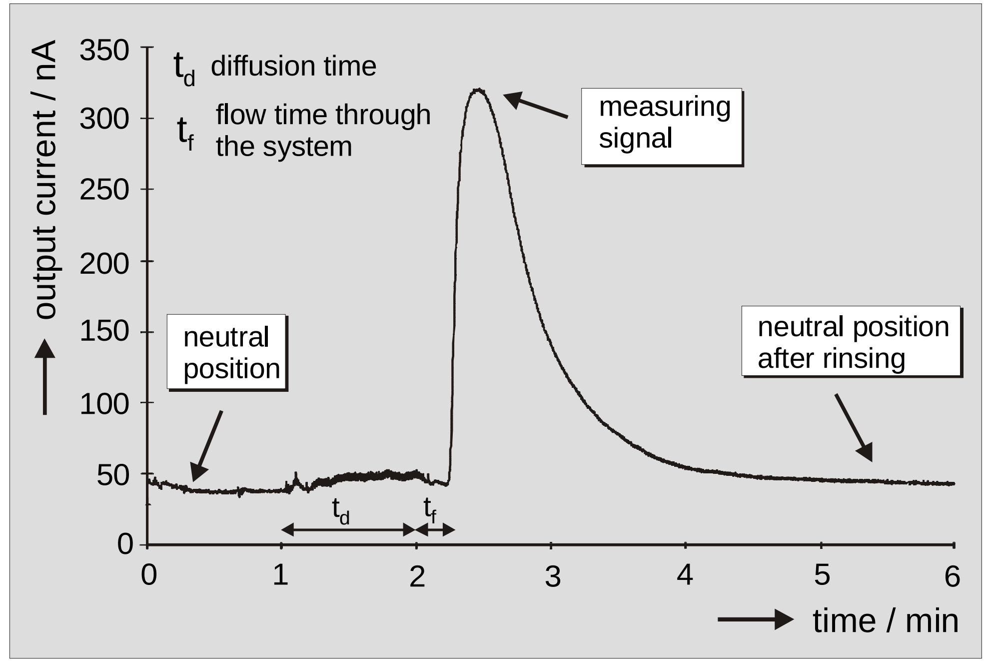
Digital Mirror Display (DMD)
Texas Instruments, Inc.



Micro flow-diffusion analysis system



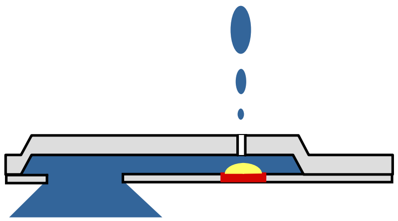




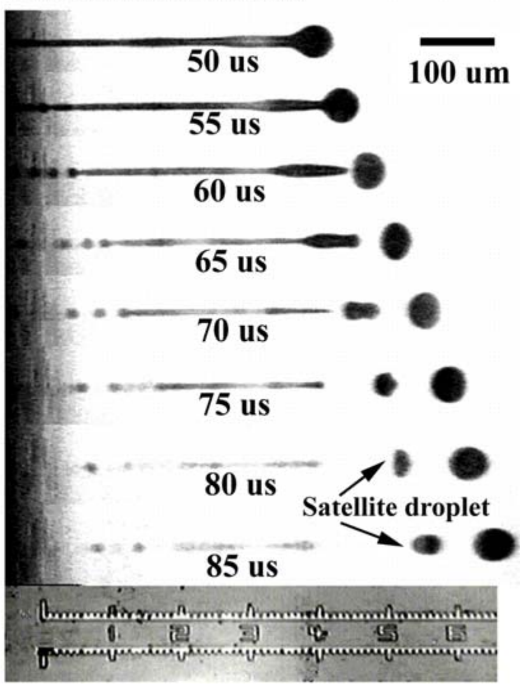
Transcutaneous measurement of blood alcohol 20 minutes after drinking of two glasses of champagne

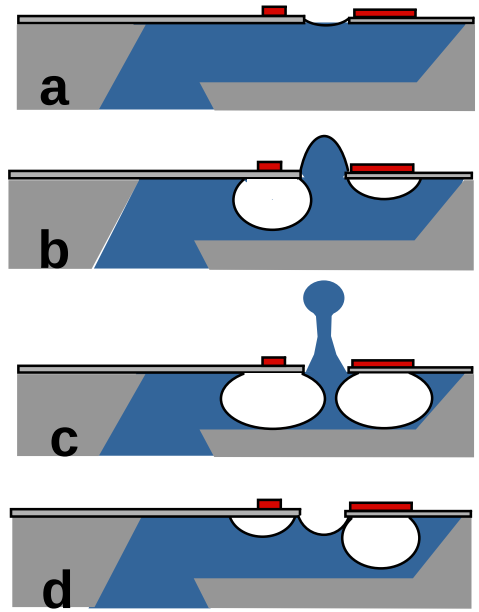
Further application: non-invasive measurements of metabolites as indicators of the physical condition

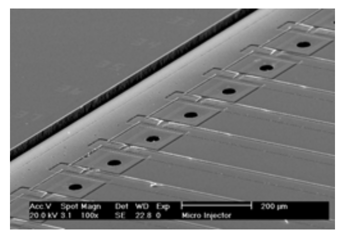
Precision Delivery of Minute Amount of Liquid

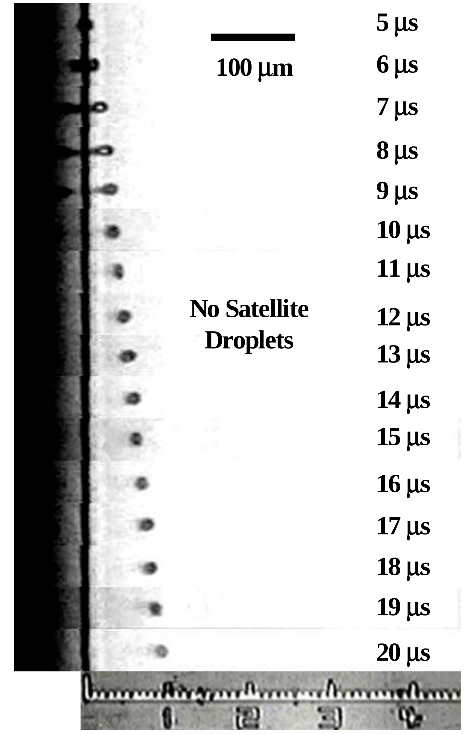


Break-off of Droplet 10V (50-85μs)









10 micron droplet
30kHz

0.5 pico-litter

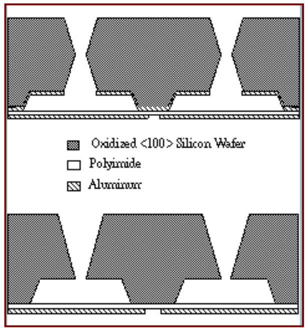
- High resolution printing
- Drug delivery

Kim, Ho

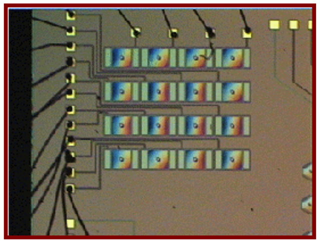
AEROSPACE MEMS APPLICATIONS WITH "HIGH-END" FUNCTIONALITY

- Complete inertial and navigation units on a single chip.
- **Inertial Measurement Units (IMU) on a chip.**
- **Distributed sensing systems for monitoring, surveillance and control.**
- Miniature and integrated fluidic systems for instrumentation and bio-chemical sensors.
- Embedded sensors and actuators for maintenance and monitoring.
- **Identification and tagging systems using integrated micro-opto-mechanical MEMS.**
- Smart structures and components.
- **Micro flow control**
- **Fuze / Safety & Arming**
- **Micro Power and Propulsion**
- Mass storage and novel display technologies.

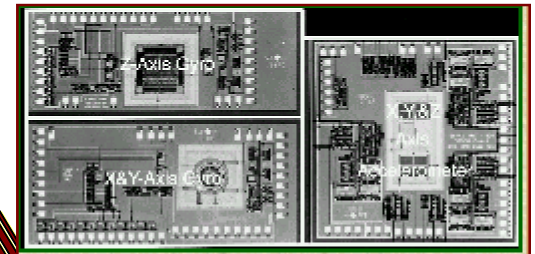
MEMS for Military Applications



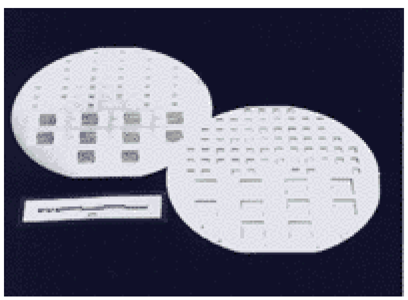
Microjet Arrays
for Airflow Control



Adaptive Optics Arrays
for Target Acquisition &
Friend or Foe ID

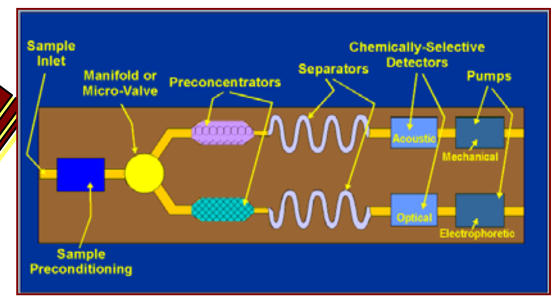


MEMS IMU
for Inertial Measurement
& Navigation



Multiple Chip Wafer Fabrication
for Graceful Degradation and Cost
Reduction

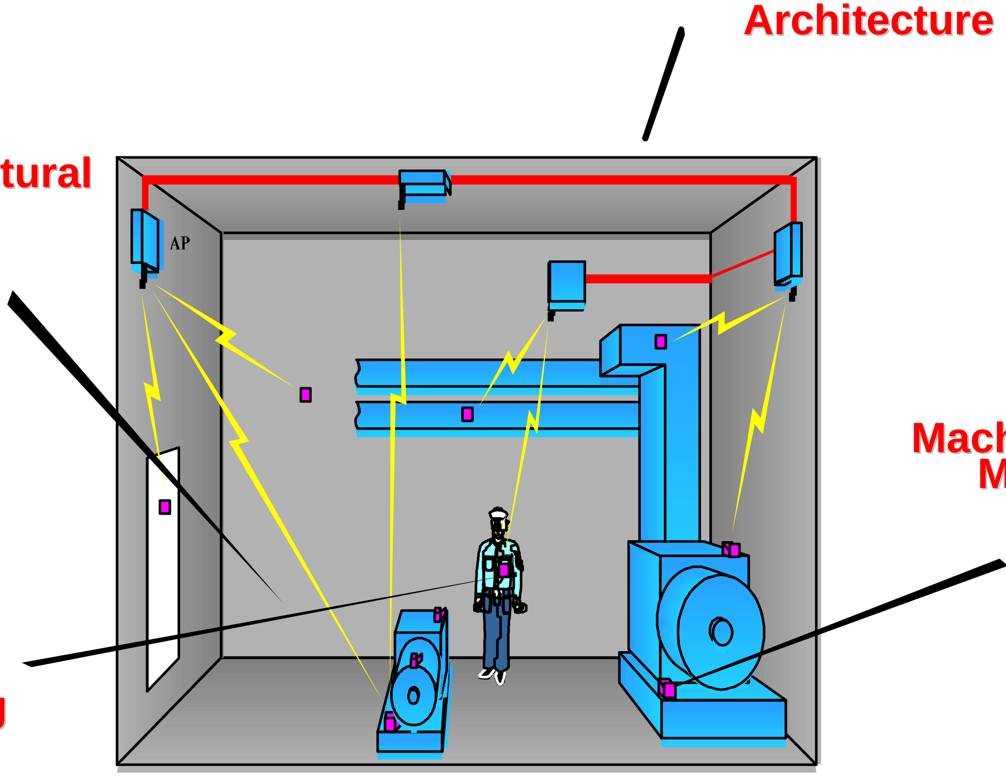
Fuze/safety
and arming



Chem-Lab on a Chip
for Forward Recon & QA

Reduced Ship's Crew by Virtual Presence (RSVP) Concept

Internal Ship Situational Awareness



BARRIERS AND CHALLENGES FOR IMPLEMENTATION

- RELIABILITY
- HARSH ENVIRONMENT
- SUPPLY AVAILABILITY
- OBSOLESCENCE
- PACKAGING
- MANUFACTURING
- LACK OF STANDARDS
- SECURITY ASPECTS

NATO RTO/AVT MEMS TASK GROUP

- APPLICATIONS, STATUS, R&D NEEDS, BARRIERS
- 2000 to 2003
  - INTERIM REPORTS, CDs FROM 3 MEETINGS
  - FINAL REPORT, SEPTEMBER 2004
  - RTO SYMPOSIUM, BRUSSELS, APRIL 2003
- FOCUS
  - HEALTH MONITORING
    - GAS TURBINES
    - MUNITIONS
  - IMU
  - MICRO FLOW CONTROL
  - FUZE/SAFETY&ARMING
  - MICRO POWER

RLS "MEMS AEROSPACE APPLICATIONS"
First Day

08:15-08:45	**Registration**
08:45-09:00	**Opening Ceremony, National Authorities**
09:00-09.30	**Dr. Klaus C. Schadow, Consultant, US, "Introduction"**
09:30-10:30	**Prof. Dr. Mehran Mehregany, Case Western Reserve University US, "Introduction into MEMS Technology (1)"**
10:30-11:00	**Break**
11:00-11:30	**Prof. M. Mehregany, US, "Introduction into MEMS Technology (2)"**
11:30-12:30	**Dr. Clyde Warsop, BAE SYSTEMS, UK, "Micro-Flow Control (1)"**
12:30-14:00	**Lunch**
14:00-15:15	**Dr. Warsop, UK, "Micro-Flow Control (2)"**
15:15-15:45	**Break**
15:45-16:45	**Prof. M. Mehregany, US, "Applications to Gas Turbines – Health Monitoring"**
16:45-17:15	**Dr. K. Schadow, US, "Micro Power"**

RLS “MEMS AEROSPACE APPLICATIONS”
Second Day

08:45-10:00	**Dr. Ayman El-Fatatry, BAE STSTEMS, UK, “Inertial Measurement Units - IMU”**
10:00-10:30	**Break**
10:30-11:30	**Dr. A. El-Fatatry, UK, “MOEMS”**
11:30-12:45	**Paul Smith, IHDIV, Naval Surface Warfare Center, US, “Fuze/Safety & Arming”**
12:45-14:00	**Lunch**
14:00-15:00	**Paul Smith, US, “Health Monitoring of Munitions”**
14:00-14:30	**Wrap-Up**